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User's Guide for the Air Force Surface-Layer Windflow Model (AFWIND)

BRUCE A. KUNKEL

8 July 1988

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HANSCOM AFB, MA 01731

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AFWIND is a two-dimensional (x-y plane) surface-layer windflow model for complex terrain. The model runs on most IBM-compatible microcomputers with enhanced graphics capability. The model accepts single or multiple observations of surface winds. The model then performs a variational analysis of the windfield, adjusting the winds through a relaxation technique until the windfield conforms to effects of topography, stability, ambient flow conditions, and mass continuity. Atmospheric stability is determined from either date/time, wind speed, and cloud cover, or from vertical temperature profile measurements. The model is designed to produce high resolution wind analyses, typically running on domains on the order of 10 x 10 km, with horizontal grid spacing of 100 to 200 m.

This report describes the structure of the computer code and the input data requirements. An example run is given.

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Contents

Illustrations

User's Guide For The Air Force Surface-Layer Windflow Model (AFWIND)

1. INTRODUCTION

This report describes the operations of a two-dimensional (x-y plane) surface-layer windflow model for complex terrain. The model is designed to run on an IBM - compatible microcomputer with enhanced graphics capability, and preferably a math co-processor.

The model is a modification to a model developed by Ball and Johnson[1] for the Army Atmospheric Sciences Laboratory (ASL) at White Sands Missile Range, New Mexico, to specify terrain-induced wind effects over small areas of complex terrain (5-20 km on a side), using high horizontal resolutions, typically between 100 and 500 m. The model was acquired by the Air Force Geophysics Laboratory (AFGL) for incorporation into a toxic chemical prediction system for complex terrain. Further model developments at AFGL included the creation of different meteorological data input options (including a cursory objective analysis for multiple observations), and the adaptation of the code to microcomputers such as the Zenith-248. The model has been tested and evaluated on various types of terrain, including the gentle topography of Ft Polk, Louisiana with complex vegetation cover (Lanicci[2]), rough terrain of South Vandenberg AFB, California with sparse vegetation (Lanicci and Weber[3]), and

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rolling terrain of Ft Devens, Massachusetts with fairly uniform forest cover (Lanicci and Ward[4]).

The basic theory and equations for the windflow model are contained in the four reports cited above and will not be repeated here. The essence of the theory is that the motion which occurs in nature takes place in such a way as to minimize constraint forces arising from kinematic conditions. The model performs a variational analysis of the windfield, adjusting the winds through a relaxation technique until the windfield conforms to effects of topography, stability, ambient flow conditions, and mass continuity.

The model accepts input of wind, temperature, cloud cover, and cloud type, and uses this information, along with the date and time, to diagnose the surface-layer stability. After performing the variational analysis, the model produces a high-resolution wind analysis over a specified area, as well as a wind speed profile up to 100 m above the ground.

2. STRUCTURE OF COMPUTER CODE

The AFWIND model is made up of two programs, MODEL.EXE and WINDPLT.EXE. MODEL.EXE is made up of three component programs, WIN.FOR, SUB1.FOR, and WFM.FOR. Each is compiled separately for ease and speed and then linked by LNKW.BAT and renamed MODEL.EXE. An include file (WIND.INC) is used to provide common variables for the three components. MODEL is coded in FORTRAN 77. MODEL creates two output files (WIND.OUT and MODIN.OUT), which are used as inputs to the graphic display program WINDPLT. WINDPLT provides screen plots of the windfield and vertical wind profile. WINDPLT is written in BASIC.

To start the program, the user types AFWIND. AFWIND.BAT then executes MODEL. Input data are archived in file INPUT.DAT for reference later if necessary. Figure 1 shows the structure of AFWIND.

2.1 Windflow Model (MODEL)

The main program MODEL calls three modules INPUTD, WFMD, and FLOUTD. INPUTD calls four subroutines directly. These subroutines input such variables as terrain heights, vegetation, or roughness heights, date and time, wind speed and direction, temperature, and cloud cover. Buoyancy and stability are then calculated. WFMD is the windflow computational module, calling five subroutines, two of them directly, to produce a high resolution, two-dimensional analysis of surface winds. FLOUTD creates two output files which contain the wind component arrays (u and v) for the domain and the model input parameters. The model provides space for a terrain array size up to 75 x 75 elements. The model requires a minimum core of

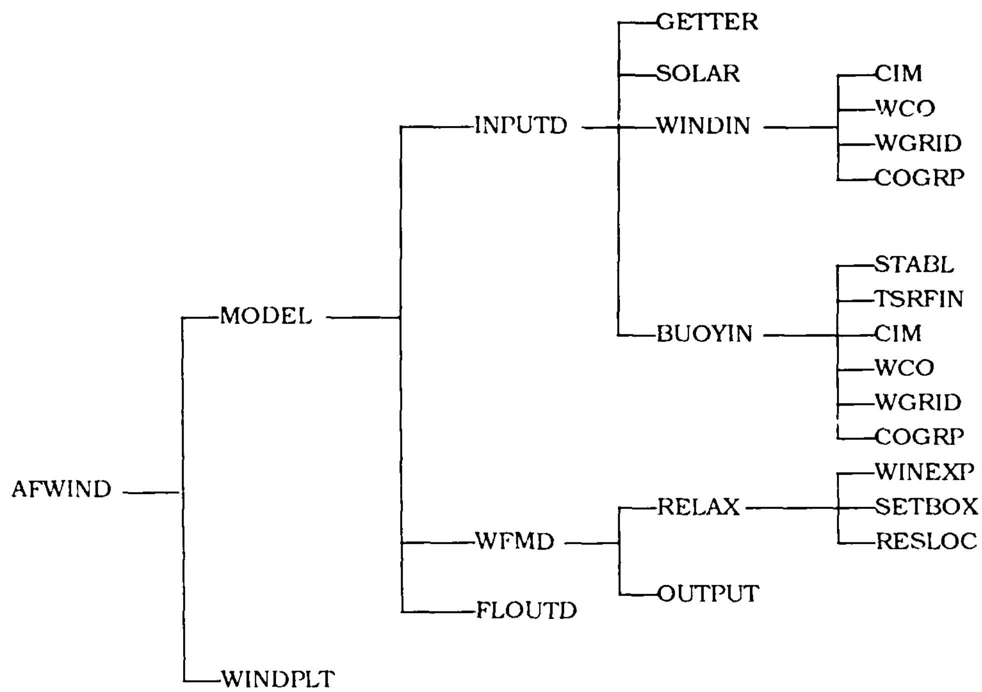

Figure 1. Structure of AFWIND.

about 448K to be run.

All subroutines access common variables made available through the INCLUDE file, WIND.INC. WIND.INC contains the allocation for array size for the model used for the terrain heights, surface roughness, wind components, wind exponents, buoyancies, and terrain slopes. This file also provides space for the wind speed and direction, surface temperature, date, time, latitude, longitude, buoyancy, and constants for other variables for the wind flow model, and common storage for the terrain input file name.

A brief description of the modules and subroutines follows.

Module INPUTD

INPUTD asks for the following information:

- Greenwich or local time
- date and time
- cloud amount and type
- type of temperature measurement (single surface observation or temperature profile(s))
- snow cover
- soil moisture (wet or dry)

INPUTD calls four subroutines directly. These are as follows:

(1) Subroutine GETTER

This subroutine inputs the terrain data arrays limits (MMX and MMY), grid spacing (DX), longitude (LON) and latitude (LAT), and surface roughness indicator (VNO) from the terrain data input file. VNO indicates the roughness information stored in the data file.

VNO=1 Vegetation heights

VNO=2 A roughness array

VNO=3 A constant roughness

The terrain and roughness data are read in from the file. If VNO=1, the terrain height is adjusted by adding 7/10th of the vegetation height to the terrain height, and the surface roughness is equal to approximately 0.14 times the vegetation height.

The calculation height for the windflow is set at 10 m (32.8 ft) above ground level (AGL). Wind measurement is assumed to be at 10 m.

The model calculates terrain slopes and creates a terrain array using the center of each four gridpoints.

(2) Subroutine SOLAR

This subroutine calculates solar elevation angle and solar radiation based on date, time, latitude and longitude.

(3) Subroutine WINDIN

This subroutine inputs wind direction in degrees and speed in knots, mph, or m/sec at one or more locations. These input winds are normally kept constant at the input point during the relaxation phase. If one wind observation is entered, the user has the option of not pegging the wind at the input point. The locations of the wind observations are defined either by gridpoint or distance (m) from the lower left corner of the domain. These winds are used to initialize wind components (u and v, in m/sec) at each gridpoint. With a single wind observation, the initial windfield over the domain is uniform. If multiple winds are used, a simple interpolation scheme is used to initialize the windfield over the domain. The wind components are rotated 45° to orient their axes along the direction of calculated terrain slopes. WINDIN calls CIM and WGRID, or CIM, WCO and COGRP for defining the wind input locations, except for a single wind measurement that is not pegged.

(4) Subroutine BUOYIN

This subroutine calculates the buoyancy at each grid point by one of two methods. If a single surface temperature measurement was indicated in INPUTD then BUOYIN calls TSRFIN to input surface temperature and STABL to calculate the stability. It then uses the surface temperature and stability to calculate buoyancy. If a vertical temperature profile is indicated in INPUTD, then BUOYIN asks for either sounding data (balloon) or temperature profile data (met tower), and uses that data to determine the buoyancy. STABL is called but only to determine the Monin-Obukhov length which is later used in WINDPLT to determine the vertical wind profile exponent. If sounding data are called for, BUOYIN asks for the number of temperature measurements in the sounding (minimum of 2), and the temperature, height, and pressure at each level. If the temperature profile data are called for, BUOYIN asks for the upper and lower temperature and the height difference. The buoyancy is then calculated and assumed constant throughout the domain. If there is more than one temperature profile measurement, the locations of the measurements (either specific gridpoint (WGRID) or distance from lower left gridpoint (WCO)) are entered. The buoyancy is then computed at all gridpoints using a simple interpolation scheme.

The following subroutines are called from BUOYIN and WINDIN.

(a) Subroutine TSRFIN

This subroutine is called from BUOYIN when no temperature profile is available. The routine inputs the surface temperature and converts it to Kelvin.

(b) Subroutine STABL

This subroutine, called from BUOYIN, calculates the atmospheric stability using the solar and wind information, as well as snow cover and ground moisture. The stability parameter varies from 0.5 (unstable) to 6.0 (stable). A value of 3.5 is neutral. The Monin-Obukhov length is also calculated and is used in WINDPLT to compute the vertical wind speed profile exponent.

(c) Subroutine CIM

This subroutine defines wind or temperature input coordinates by either 1) distance from lower left gridpoint or by 2) gridpoint number (i,j).

(d) Subroutine WGRID

This subroutine asks for the gridpoint locations of the wind or temperature profile measurements.

e) Subroutine WCO

This subroutine asks for the x, y distances (in m) from the lower left gridpoint of the wind or temperature profile measurement.

(f) Subroutine COGRP

This subroutine is used in conjunction with WCO. The distance specified in WCO is converted to the nearest grid point location.

Module WFMD

In WFMD, the initial windfield established in WINDIN is adjusted to a terrain-induced windfield through a series of relaxation steps. WFMD sets the minimum number of relaxation steps at 2 and the maximum number at 60. It displays the array size in the terrain data file and allows a choice of a smaller array window for the windflow calculation. *To avoid boundary effects, especially on small grids (for example 10 x 10), a slightly larger grid than the domain of interest should be used.* WFMD also displays the current relaxation step and tests to see if constraint has reached minimum. This module calls two subroutines directly.

(1) Subroutine RELAX

RELAX is the workhorse of the windfield analysis. It accomplishes the following:

- calls routines to calculate local contributions to the acceleration residual.
- accumulates residuals
- calculates partial derivatives of residuals with respect to wind components at each gridpoint
- applies incremental adjustments to the wind field

RELAX calls three subroutines.

(a) Subroutine WINDEXP

WINDEXP computes the wind profile exponent at each gridpoint. The wind profile exponent is a function of the buoyancy defined in BUOYIN.

(b) Subroutine SETBOX

SETBOX selects the parameters for the local residual.

(c) Subroutine RESLOC

RESLOC calculates the integral of the residual squared over a local volume element (flux box).

(2) Subroutine OUTPUT

OUTPUT rerotates calculated wind components 45 degrees to return to the original Cartesian coordinates.

Module FLOUTD

FLOUTD creates two formatted output files to be used by the utility plotting routine to display output on the screen. These files are:

WIND.OUT--contains u, v component arrays for a size MX (west-east) by MY (south-north).

MODIN.OUT--contains model input and output parameters. These are day, month, year, time, wind direction and speed, surface temperature, cloud cover, cloud type, Monin-Obukhov length, stability parameter and average buoyancy and surface roughness over window.

2.2 Wind Plot (WINDPLT)

This routine displays the windfield over a selected window which would be the same size as, or smaller than, that specified in WFMD. If any part of the selected window is outside the area specified in WFMD, the program will ask you to stay within the specified area. The winds can be displayed either as arrows with length proportional to speed or with barbs, each half barb equal to 5 knots, 5 mph, or 2.5 m/sec. A maximum of five barbs is shown. The plot displays the date/time, mean wind direction and speed and mean buoyancy.

The user has the option of plotting the terrain contours. However, a contour data file must have been established beforehand. This is done with ISOPL.EXE. This program defines the contours and their positions, and stores the information in the contour data file. For more information on ISOPL see Section 3.2.

After the wind plot is completed, the user may (1) plot a different size grid, (2) produce a vertical windspeed profile plot, or (3) terminate the program. If the second option is chosen, a plot of the vertical windspeed profile from 32.8 ft to 300 ft is displayed if the user selects the speed in kt or mph option, or from 10 m to 100 m if the m/sec option is selected. A power law profile is assumed and the exponent used is based on the Monin-Obukhov length calculated in STABL. The plot displays the date/time, mean direction and speed at 10 m, temperature, cloud cover, cloud type, stability parameter, maximum windspeed in the layer, mean windspeed of the layer, and the profile exponent.

3. INPUT DATA REQUIREMENTS

3.1 Meteorological Data

AFWIND requires meteorological data as input, and the availability of a terrain data base. The meteorological data requirements are:

(1) Wind direction and speed (10 m) at one or more locations
(2) Single surface temperature, or
(3) Vertical temperature profile consisting of either:
  1 sounding which includes temperature, height above sea level, and pressure at two or more levels, or
  1 or more sets of temperature measurements at two different heights
(4) Cloud amount in eighths
(5) Cloud type

(6) Snow cover (yes or no)

(7) Ground moisture (wet or dry)

Figure 2 is a schematic showing the flow of meteorological input data. Generally, one wind measurement is sufficient. *Best results occur if the wind measurement is in a relatively open area where the wind is not affected appreciably by the terrain.* With one wind measurement, the user has the option of keeping the wind fixed at that location or letting it vary as it goes through the relaxation steps. If multiple wind measurements are used the winds remain fixed at the stated locations. Wind speeds less that 1 mph, knot, or m/sec are not acceptable. If a wind speed of less than 1 is entered, the operator will be asked to enter another value.

The derived windfield is very much dependent on the buoyancy. The buoyancy is a function of the vertical temperature profile. If a single surface temperature is entered instead of a temperature profile, a stability parameter is computed using the solar, wind, cloud cover, snow cover, and ground moisture information. A vertical temperature gradient is then derived from the stability parameter and used to calculate the buoyancy.

If sounding data are used, there is no need to enter temperature data from more than one level above the highest terrain point, since the buoyancy at a grid point is based on the temperature gradient at the elevation of the gridpoint. It is assumed that the sounding is applicable to the entire domain. The temperature, height, and pressure data for the lowest level, which should be at ground level, are entered first. Generally, only the two lowest levels of a sounding are necessary. In this situation, the height data are not used, as the model assumes that the temperature gradient, and consequently the buoyancy, is the same at all elevations throughout the domain. If more than two levels are entered (therefore more than one temperature gradient), the height data are used to determine which temperature gradient applies to which grid point. A maximum of five levels is allowed.

If the temperature gradient is derived from two temperature sensors mounted on a single tower, then that gradient applies to the entire domain, even if part of the domain is above the highest measurement. If there are temperature data from more than one tower, a simple interpolation scheme is used to determine the buoyancy throughout the domain.

If data are available from more than two levels of a single tower, this must be treated as a sounding. However, pressure data would have to be measured at each level. The model cannot handle multiple towers with more than two levels of data.

Cloud type is input only for daytime conditions, as the type of cloud does not affect the stability at night. The cloud types have been condensed into three groups representing high, middle and low clouds. The cloud groups are as follows:

High--Cirrus, Cirrocumulus, Cirrostratus

Middle--Altocumulus, Altostratus, Stratocumulus, Cumulus

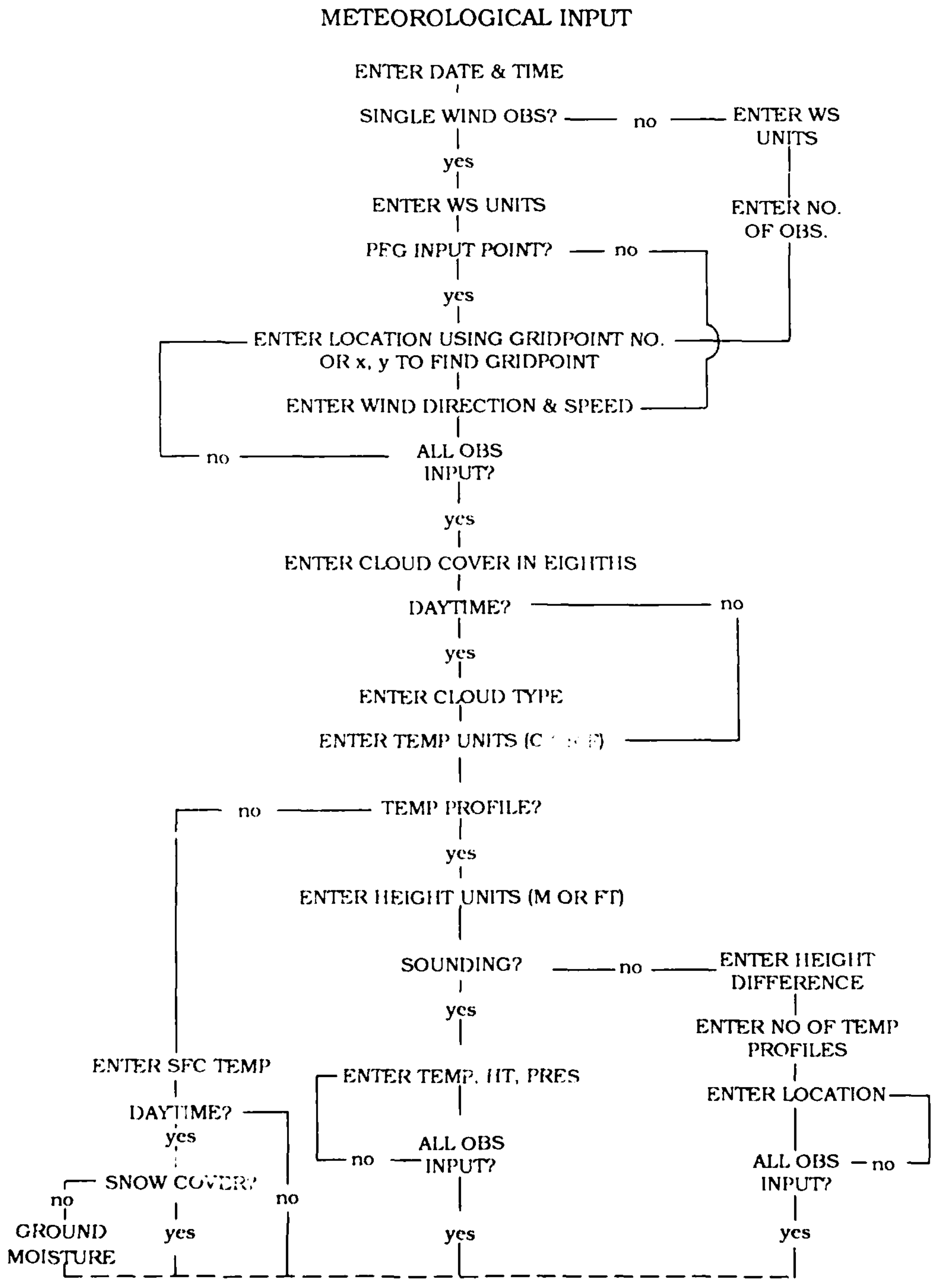

Figure 2. Flow Diagram of Meteorological Input Data

Low--Stratus, Nimbostratus, Fog

Snow cover and ground moisture are input only for daytime conditions. Snow cover is not asked for if the surface temperature is greater than 20° C (68°F). Ground moisture is not asked for if there is snow cover.

The meteorological input data are stored in INPUT.DAT for later retrieval and print out.

3.2 Terrain Data

The terrain data file contains the domain size, grid spacing, the latitude and longitude, and the terrain height in meters at each grid point. It also contains either the vegetation height (m) or surface roughness (m) at each grid point or a mean roughness (m) for the entire domain.

The data file has the following structure:

Record 1 = MMX, MMY, DX, LON, LAT, VNO where MMX and MMY are the number of gridpoints in the east-west and north-south direction, respectively. DX is the grid spacing in m. LON and LAT are the latitude and longitude. LON and LAT are each three word arrays for degrees, minutes, and seconds. Normally, rounding off to the nearest whole degree is sufficient. VNO is the roughness indicator.

Record 2 = ((H(I, J), I=1, MMX), J=1, MMY), and

If VNO = 1 ((V(I, J), I=l, MMX), J=1, MMY), or

If VNO = 2 ((R(I, J), I=1, MMX), J=1, MMY), or

If VNO = 3 CROUGH

where H is the terrain height, V is the vegetation height, R is the roughness height, and CROUGH is a mean roughness for the domain. If the vegetation height data are entered (VNO=1), then the surface roughness is equal to roughly 0.14 times the vegetation height.

A program called TER.EXE makes it easy for the user to set up a terrain data file. The program asks for the following information:

Name of terrain file

Number of points per row and column

Size of grid spacing (m)

Latitude

Longitude

Terrain heights in meters at each grid point starting in lower left corner

One of the following:

- vegetation height at each gridpoint
- roughness height at each gridpoint
- mean roughness over domain

ISOPL.EXE is a program, written in FORTRAN, for setting up a terrain contour file. With a terrain contour file, the contours may be drawn on the windfield plot. ISOPL.EXE asks for the name of the terrain data file. It then displays the dimensions of the grid, and the largest and smallest terrain heights in the data file. You are then instructed to enter the lowest contour line that you wish drawn and the height intervals between lines. The program then calculates the positions of the contour lines, and stores that information in the terrain contour file.

4. OUTPUT

Output consists of a plot of the terrain-induced windfield over the domain of interest. Wind arrows or barbs may be used to depict the windfield. Terrain contour lines may be drawn as an option. Figure 3 shows the terrain induced windfield over South Vandenberg AFB CA using the wind arrow option. Also shown are the date and time, the mean buoyancy, wind speed and direction over the grid and the coordinates of the grid. The screen plot may be dumped to the printer if the proper PSC utility program has been located before running WINDPLT.

The user has the option of plotting the vertical wind profile up to 100 m (300 ft) as shown in Figure 4. This is based on the assumption of a power law wind profile. The exponent of the power law is a function of the atmospheric stability, computed in AFWIND, and varies from approximately 0.14 for very unstable conditions to 0.84 for very stable conditions. *The wind profile shown for stable conditions (positive buoyancy) should be used with caution.* Under stable conditions, winds at different levels can be completely independent of each other. The wind at 10 m is often strongly influenced by surface features, whereas the wind at 100 m may be controlled by the free-air flow. Wind directions at different levels on clear nights can be in completely different directions.

Also shown with the profile plot are the date and time, the mean surface (10 m) wind direction and speed over the domain, the surface temperature, stability, cloud cover and type, the wind speed at 100 m (300 ft), the mean wind speed in the layer between 10 and 100 m (30 and 300 ft), and the exponent of the power law equation.

All input data are stored in INPUT.DAT. With a PRINT command, these data may be dumped to the printer. Figure 5 shows an example of the input data stored in INPUT.DAT.

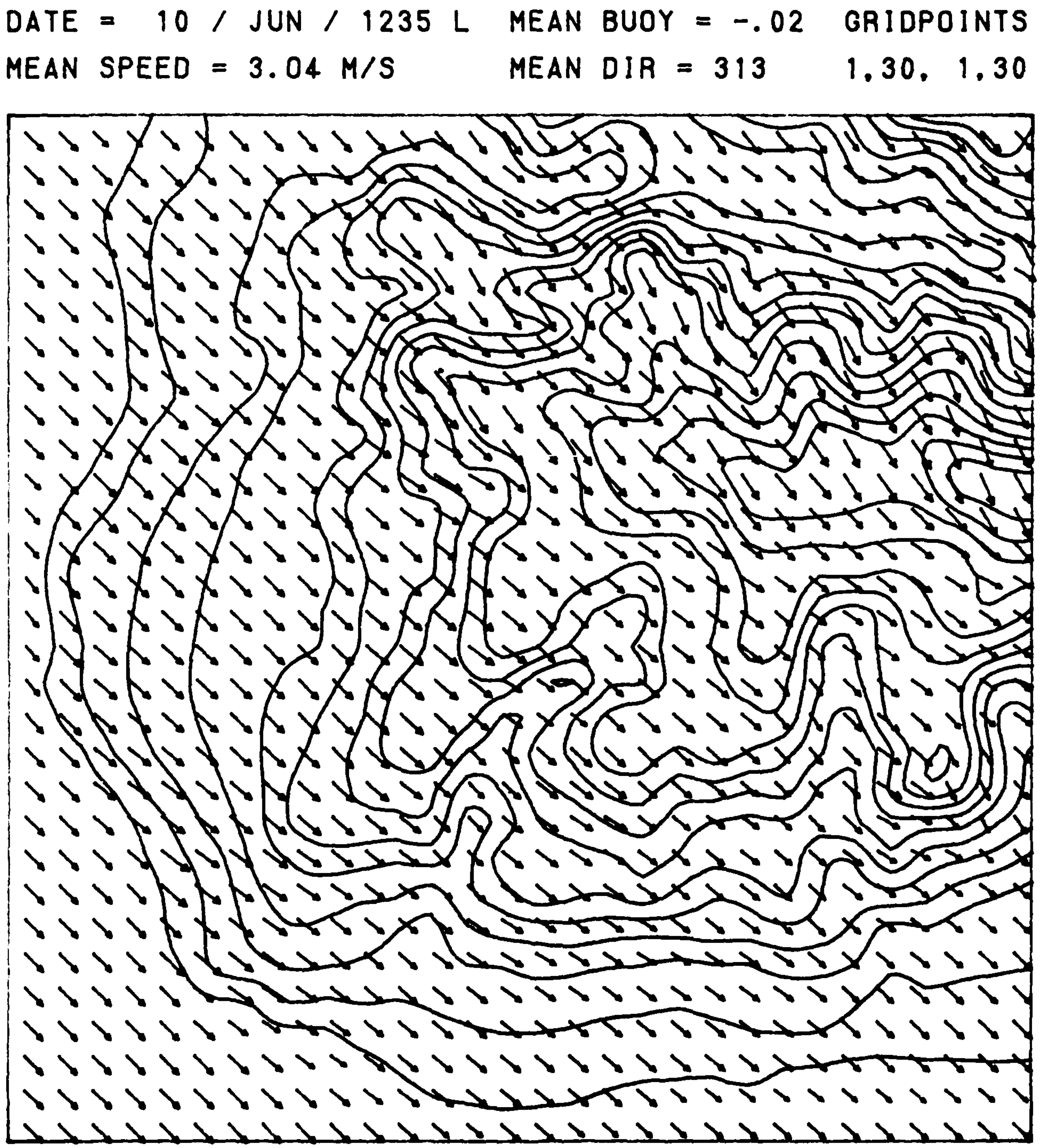

Figure 3. Model Windfield Showing Wind Velocity Arrows for Unstable Case Over South Vandenberg AFB, CA. The Solid Lines Represent Terrain Elevation Contour Lines.

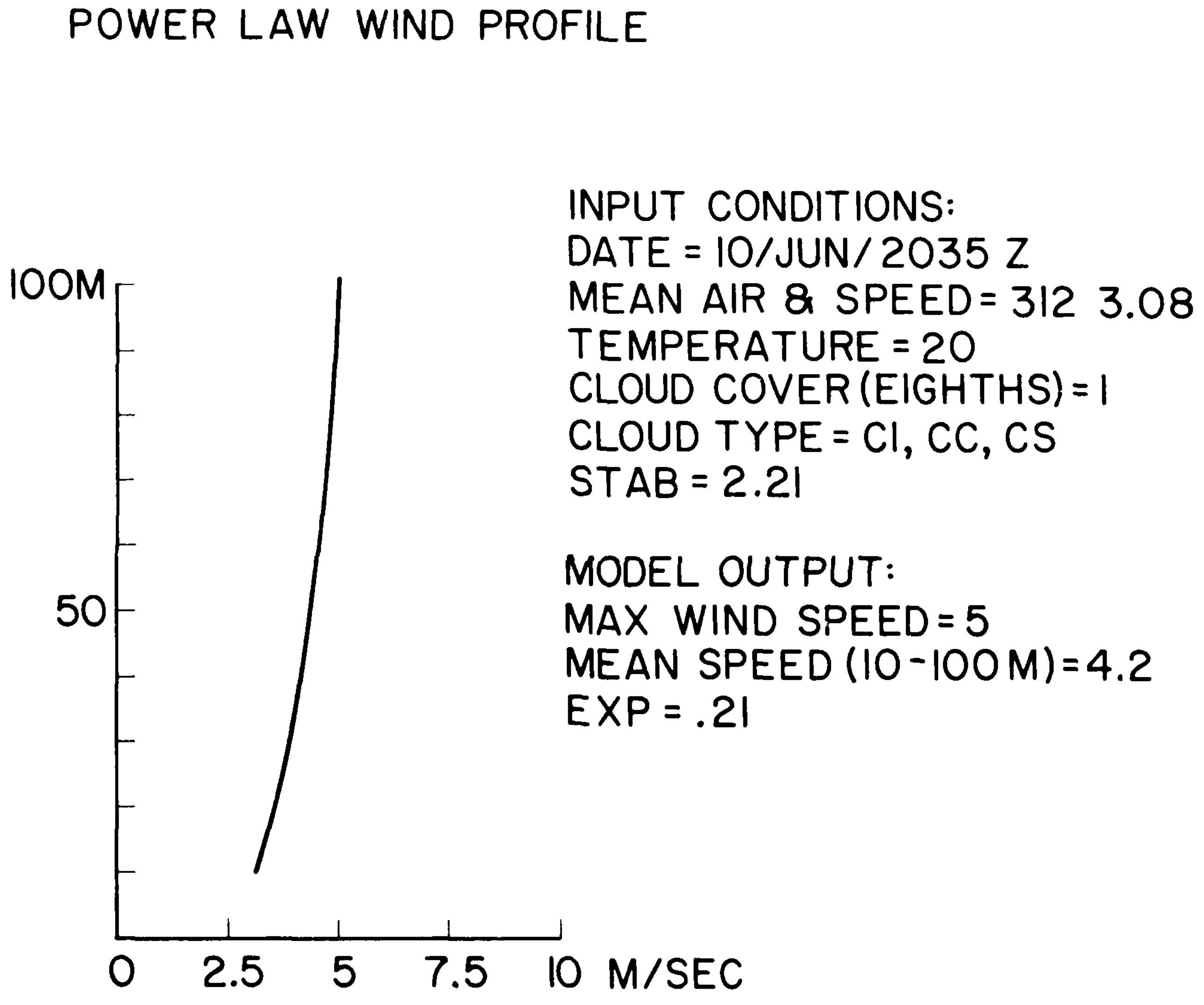

Figure 4. Model Windspeed Profile Through Lowest 100 m
for the Same Case as Shown in Figure 3.

```
AFWIND - THE AFGL WINDFLOW MODEL
THE DATA FILE USED WAS van.dat

DOMAIN : WEST TO EAST       = 1 TO 56
       : SOUTH TO NORTH     = 1 TO 61


GRID SIZE = 200. METERS


DATE-TIME = 10  6  1987  20  35  GMT


THE WIND IS NOT KEPT FIXED AT THE INPUT POINT
WIND SPEED INPUT WAS 3.0 METERS/SEC
WIND DIRECTION WAS 315.0

CLOUD COVER = 1/8
CLOUD TYPE = HIGH - CI, CC, CS

SURFACE TEMPERATURE = 20.0 C
GROUND CONDITIONS ARE DRY
DOMAIN SIZE =  1    30    1    30
```

Figure 5. Example of Input Data Stored in INPUT.DAT

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